GEOMETRICAL MAGNETO-RESISTANCE MEASUREMENT OF VERTICAL CONDUCTIVITY IN GaN AND COMPARISON WITH LATERAL TRANSPORT

by

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Peculiar phenomena in electrical transport properties of GaN include a decrease in electron mobility when the carrier concentration is decreased, a huge UV photoconductive gain, and an apparent immunity of radiative transitions to defects. In high quality samples, scattering of carriers by charged dislocation lines could explain these effects, and provide a good fit to the temperature dependent Hall effect measurement [1]. In samples with large dislocation densities and low free carrier concentration, lateral transport measurements show that the conductivity is thermally activated, and an alternative explanation, the Grain Boundary Controlled Transport (GBCT) model, seems to better fit the experimental result [2].

Although the temperature dependence of the conductivity in these two models is basically different, there must be no conflict between these two descriptions. They may merge into each other according to the density of dislocation lines *perpendicular* to the direction of the electrical current, in the following way: if the average distance between dislocations to be crossed by the carriers is d_{dis} and their corresponding depletion radius is w_{dis} , then, for $w_{dis} \ll d_{dis}$ the dislocations can be considered "isolated" scattering lines (1D) embedded in a bulk conducting film [1]. On the other hand, for more defected samples, when $w_{dis} \approx d_{dis}$, the depleted regions may connect many dislocation lines to form extended (2D) depletion regions decorating a closed volume [2]. The large variation in electrical properties of GaN reported by various researchers, which seem to be sample dependent, may well reflect the presence of these two regimes. Since GaN exhibits a columnar microstructure, and since the scattering by dislocation line charges is angular dependent, it is possible to observe both transport regimes in the same sample, by performing *in-plane (lateral) and perpendicular to the layer plane (vertical)* conductivity measurements.

In this work, we measured vertical mobility of GaN by Geometrical Magneto-Resistance (GMR), and lateral mobility by Hall effect measurements. A large difference between the lateral and vertical mobilities and their temperature dependence was obtained. The experimental results, showing a large anisotropy, can be joined into a comprehensive transport model that includes the previous ones as particular cases.

The GaN films used in this work were grown by MOCVD on (0001) sapphire substrates, at a pressure of 100 Torr and at temperature of 1050 ^{0}C, after a deposition of a thin GaN buffer layer at a lower temperature (550 ^{0}C). A thin AlGaN barrier layer was introduced above the buffer layer to prevent perturbation in the lateral electrical measurements by the shunt conductance at the substrate-buffer interface. For GMR measurements, a 2000A Si doped ($5*10^{18}$ cm^{-3}) n type GaN contact layer was grown after the buffer layer. On top of this contact layer, the main film (2 micrometers thick) of undoped GaN was grown. Two different device structures were processed: *i*) a standard Hall bar was implemented using dry etching down to the sapphire substrate; *ii*) a GMR mesa structure (200*200 μm^2) was implemented using dry etching down to the Si doped contact layer. Standard ohmic (Ti/Al/Ni/Au) contacts were implemented by lift-off metallization. Large ohmic contacts were deposited on top of the mesa GMR structure and on the contact layer.

Temperature dependent Hall effect measurements (magnetic field B=6 KG), in the 15-300K range, were performed to study the lateral transport of "as grown" samples. Ion implantation was used to produce radiation-induced compensation of carriers, to increase w_{dis}, and Hall measurements performed in the range 77 ^{0}K to 800 ^{0}K, vs implantation dose.

In the GMR samples a metal electrode covers the mesa (width W). A bottom electrode is deposited on top of the exposed n$^+$ Si doped layer. The vertical distance between the electrodes, L, is the thickness of the GaN sample. Since in this case L $\ll$ W, the Hall field is shortened by the contacts, the Lorenz force is no longer compensated, and the GMR is observed. Thus the GMR enables the use of a two terminal device for extraction of electron mobility values from the current dependence on the magnetic field. Unlike in physical magneto-resistance, the GMR effect is purely due to the boundary conditions. GMR measurements were performed (B = 7 T) in the 15-300 ^{0}K range to study vertical transport in samples of various dislocation densities. The carrier concentration was calculated from the measured mobility.

In samples with high dislocation density ($N_{dis} \approx 10^{10}$ cm^{-2}), the lateral mobility at room temperature is low (70-100 cm^2/Vs), and nearly temperature independent in the 300-150 ^0K range, and decreases with further decrease in temperature. When the free carrier density is reduced by radiation-induced damage, the lateral conductivity becomes thermally activated. The measured activation energy *vs* reciprocal carrier concentration is presented in Fig. 1. The two separate regimes observed in Fig. 1 are easily understood based on the Grain Boundary Controlled Transport model [2]. These results can not be predicted by, and are not consistent with, the dislocation scattering model.

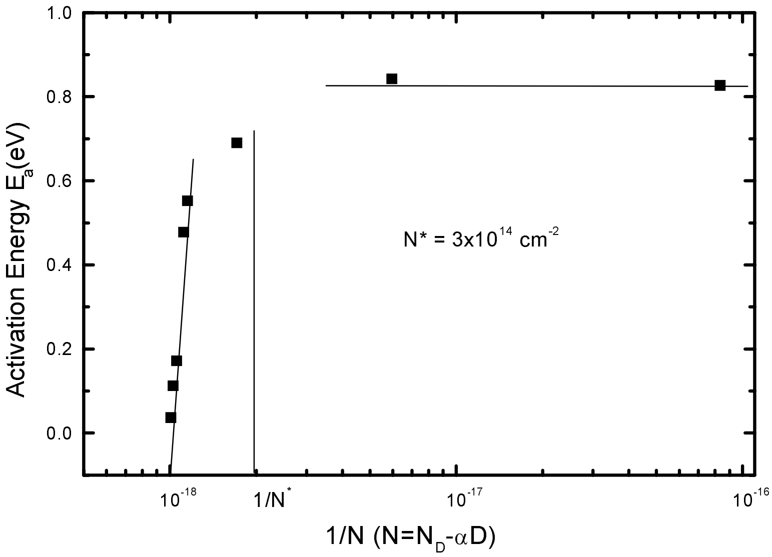

Fig. 1: Activation energy of electrical conductivity in GaN *vs* reciprocal carrier concentration. Two separate regimes are clearly observed

The vertical transport as measured by GMR on non implanted sample, exhibits electron mobility with the "usual" bell-shaped temperature dependence. The peak mobility is at a *lower* temperature than that predicted by Look and Sizelove [1]. Fig. 2 shows the temperature dependence of electron mobility in lateral, and vertical direction. The carrier concentration deduced from the GMR measurements is one order of magnitude lower than that obtained by Hall measurements. This effect may be related to lateral confinement of carriers by the potential barriers around dislocation lines (depletion cylinders), requiring volume re-calibration.

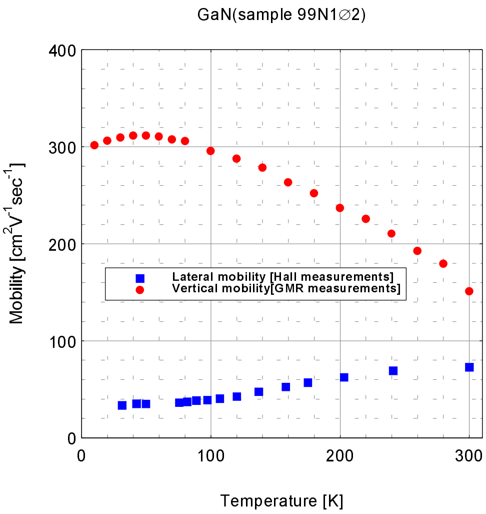

Fig.2 Lateral and vertical mobilities as function of temperature.

The strong anisotropy observed, and the quantitative details of the measurements, can not be explained by the conventional models. An orientation-dependent transport description is suggested, based on the columnar microstructure of GaN, and on existing models for transport in the different regimes.

1. **D. C. Look and J. R. Sizelove, Phys. Rev. Lett.** 82, **1237 (1999).**
2. **J. Salzman, C. Uzan-Saguy, R. Kalish, V. Richter, and B. Meyler, Appl. Phys. Lett.** 76, **1431 (2000).**